Top Production and Properties at CDF

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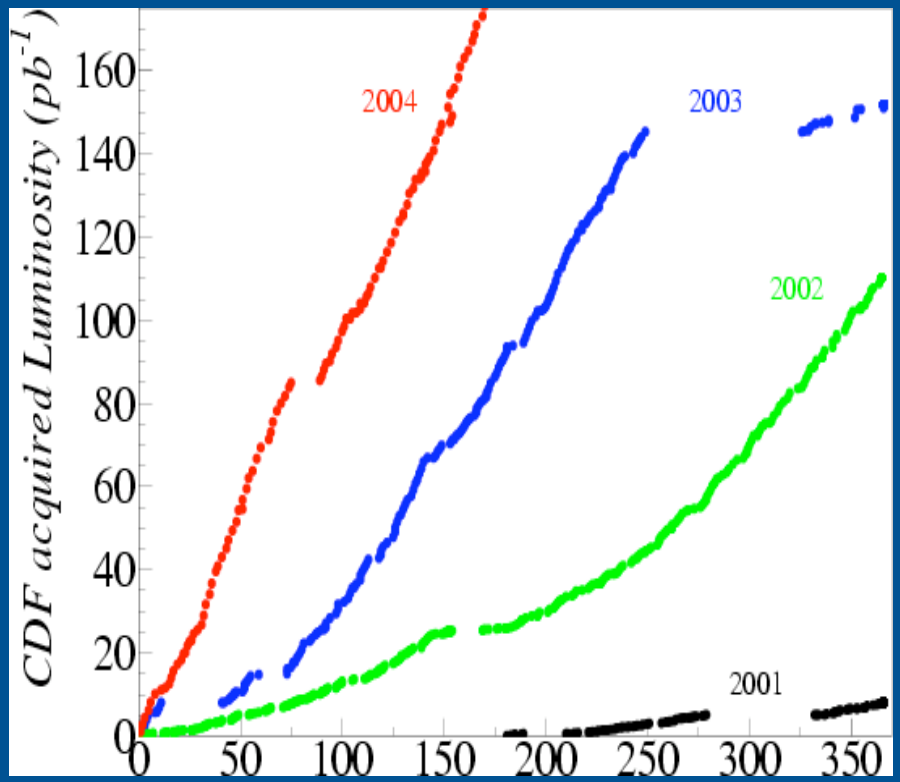
BEACH, Chicago, 2004

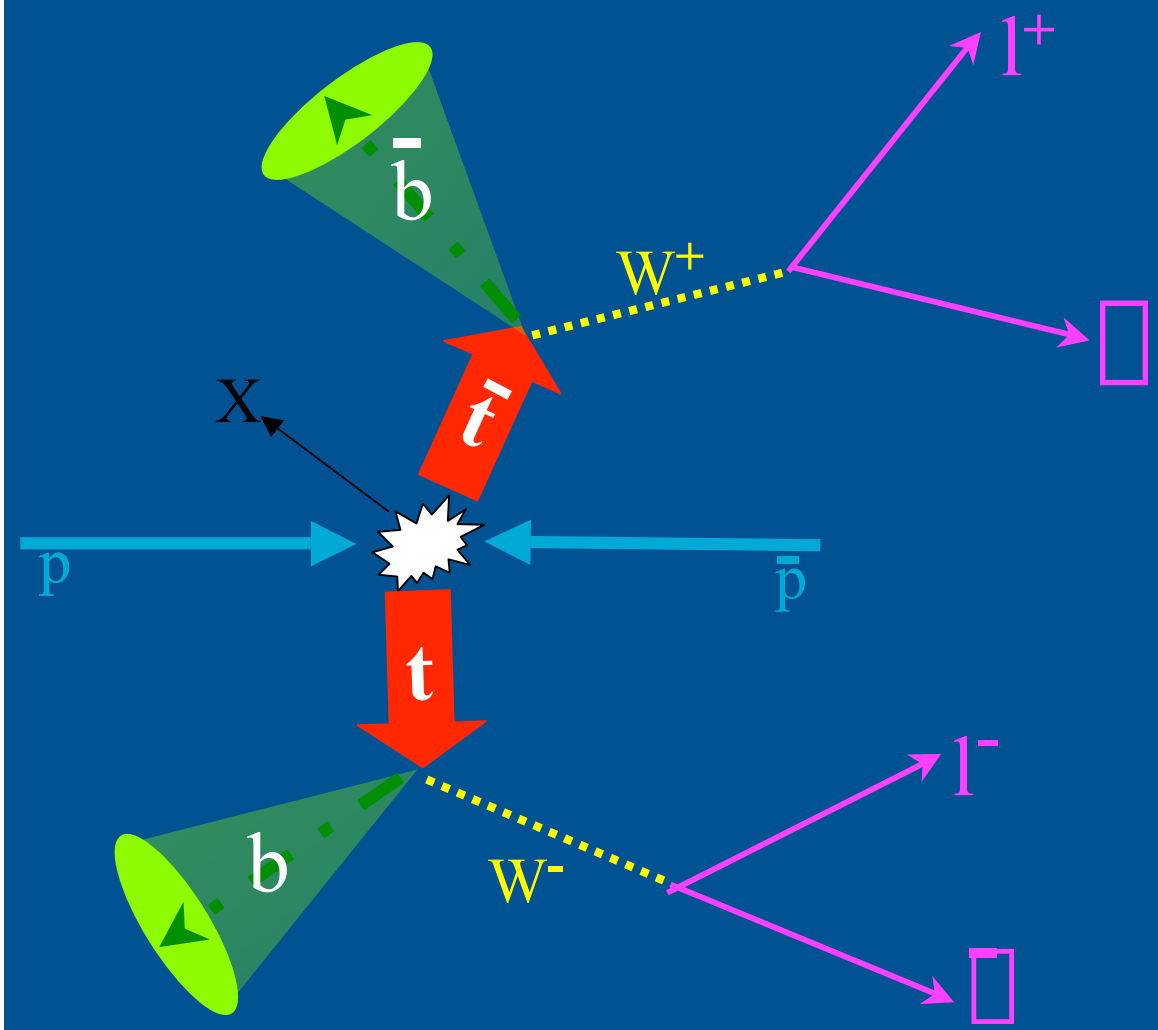
- Events are triggered on one high-momentum lepton or on jets
- We use data collected up to 9/2003, corresponding to 197 pb^{-1}
  - (cf ~108 pb^{-1} Run I)
  - 400 pb^{-1} collected so far in Run II
  - 4.5 - 8.5 pb^{-1} expected
- Additionally
  - $\sqrt{s}$ 1.8 TeV → 1.96 TeV
  - Electron acceptance
    $|\eta| < 1 \rightarrow |\eta| < 2$

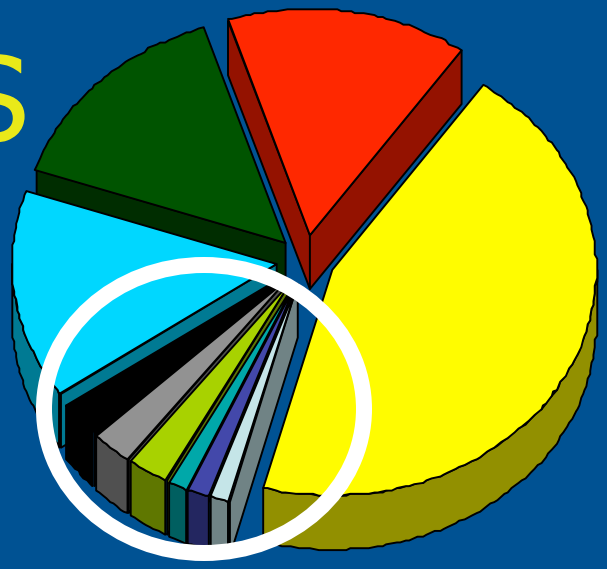
→ expect more than twice Run I yield



Measure cross section in all decay channels to test SM and to establish top data set; then test kinematics and V-A, measure M_{top} and BR's and search for resonant or single top production, and much more…

DILEPTONS





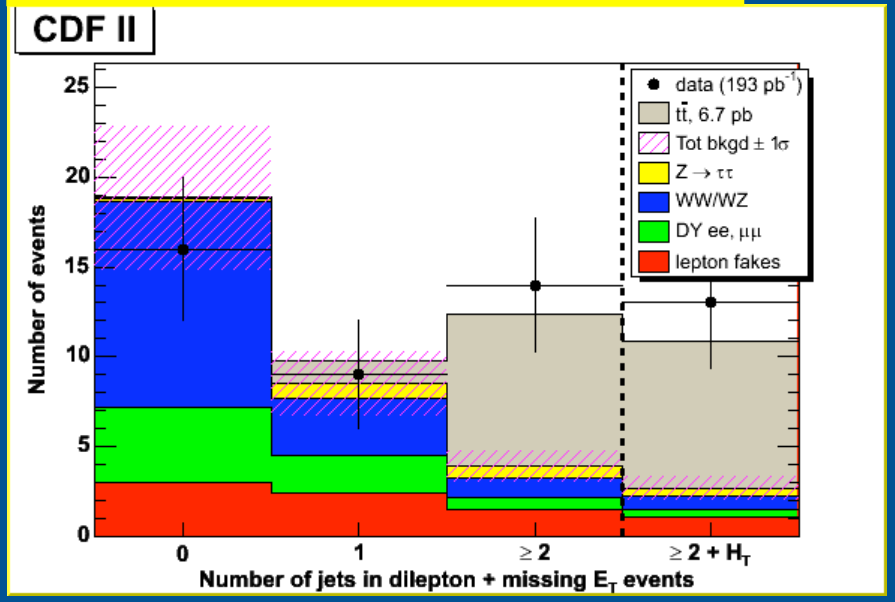
- Two high-momentum, opposite-sign leptons
  - (e,μ, some) from W decay
- 2 b jets
  - Heavy flavor ID *not* used for this analysis
- Large missing energy (E_T^{miss})
  - Two escaping neutrinos

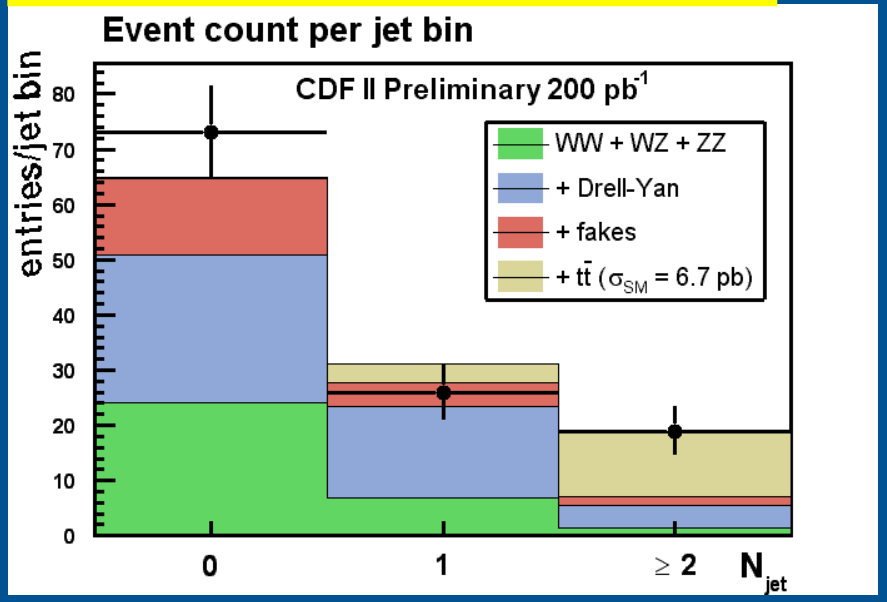
Results from counting experiments

Submitted to PRL (hep-ex/0404036)

Standard Run I method: ee/e□/□□

Looser selection: increase overall and □acc.

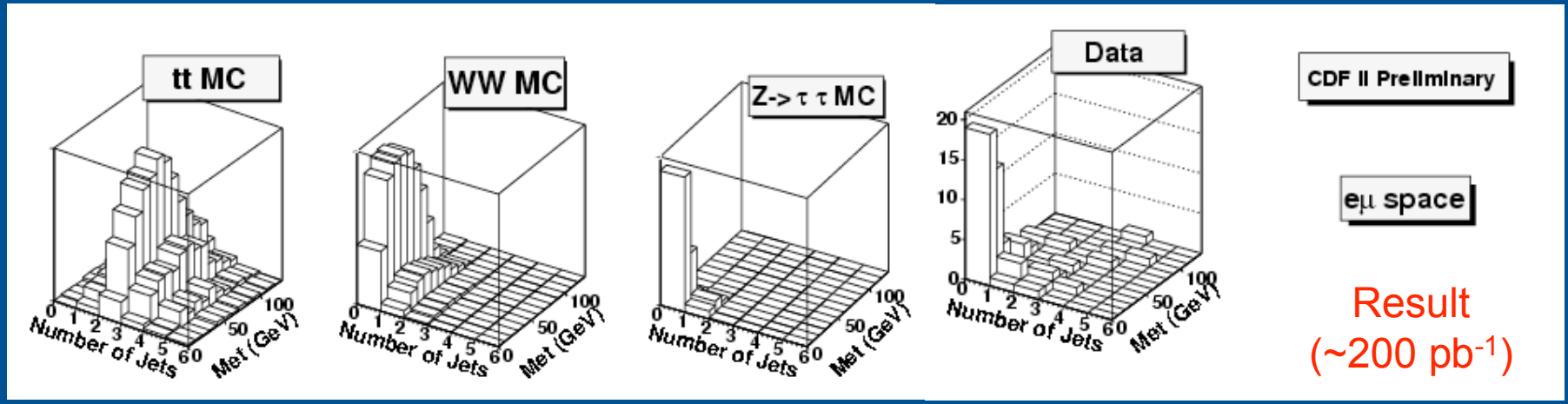




$$\square(t\bar{t}) = 7.0^{+2.4}_{\square 2.1}(stat)^{+1.6}_{\square 1.1}(syst) \pm 0.4(lum)\ \text{pb}$$

Results from Inclusive Dilepton Analysis

- New CDF technique to measure σ_{tt} in dileptons
- No cuts other than two-lepton requirement
  - If same-flavor, $Z \rightarrow ee, \mu\mu$ dominates → require significant E_T^{miss}
- Fit data for tt, WW, $Z \rightarrow \tau\tau$ contribution in 2D (E_T^{miss},N_{jet}) plane



$$\sigma(t\bar{t}) = 8.6^{+2.5}_{-2.4}(stat) \pm 1.1(syst)\ \text{pb}$$

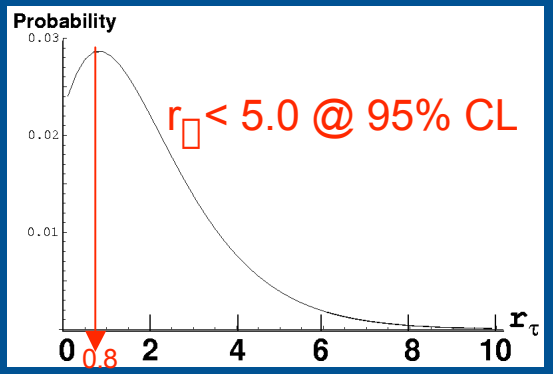
First Look at □s

- □s are more complicated to reconstruct than e's and □'s
- BR(□□ hadrons) □ 65%, difficult to distinguish from low-multiplicity jets
- Cleanest signature in dilepton channel, reconstruct events like: tt □ l□ □$_h$□ bb

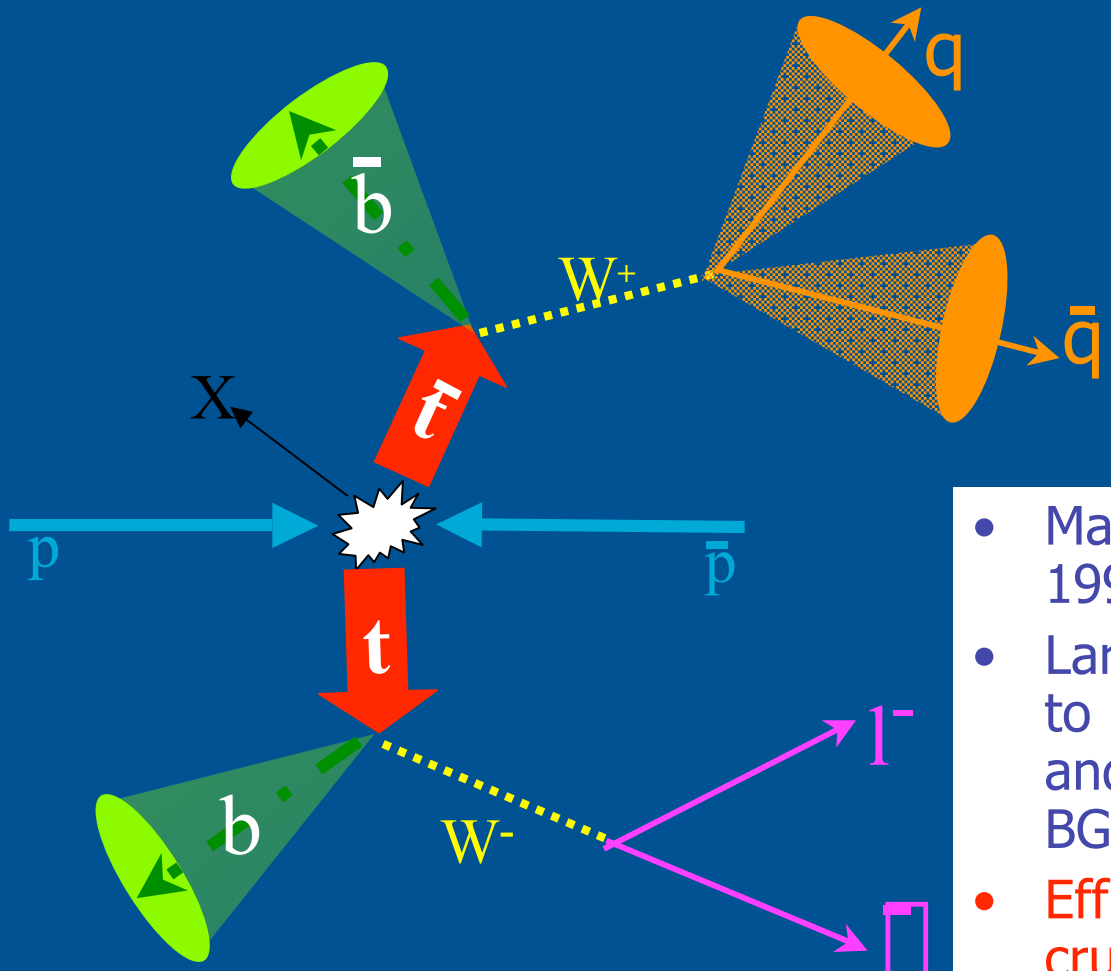
Results:

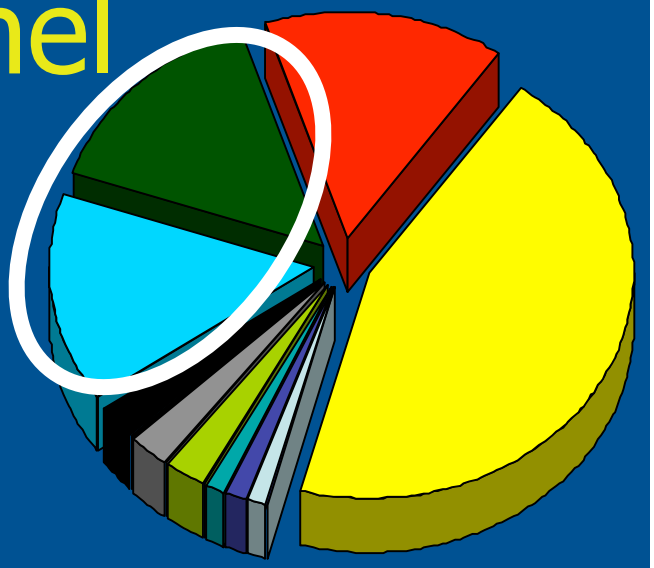
	e□	□□
Total bkgd	0.77±0.18	0.53±0.11
tt (□=6.7 pb)	0.59±0.11	0.47±0.08
Data (193 pb^{-1})	2	0

$$r_{\square} = \frac{BR(t \square\ b\square\square)}{BR_{SM}(t \square\ b\square\square)}$$



Lepton+Jets
The "Golden" Channel

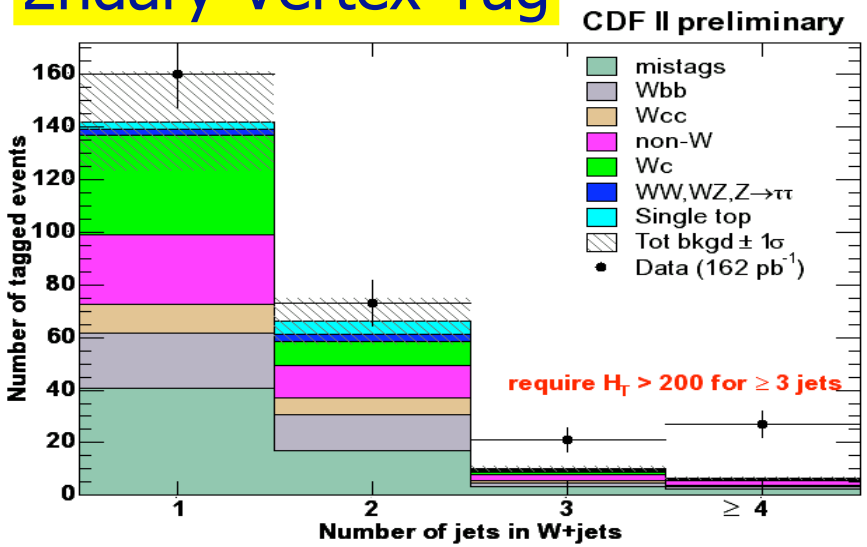




- Main channel for top discovery in 1995
- Large BR and high-pt lepton lead to large statistics, efficient trigger and relatively clean signal (main BG is from W+jets)
- Efficient and pure b-tagging crucial

Results from Counting Experiments

2ndary-Vertex-Tag



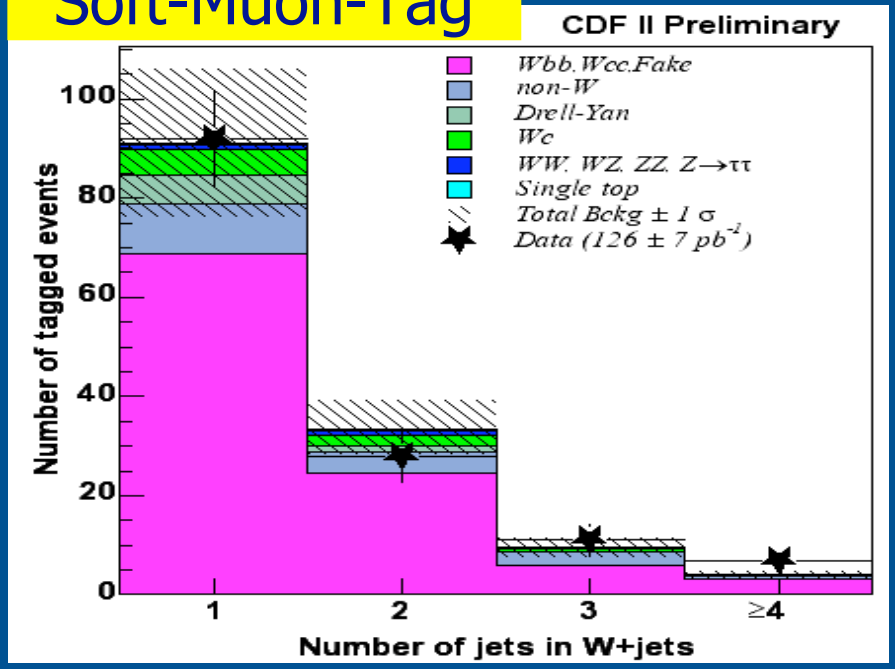
σ (single tag)=

$5.6^{+1.2}_{-1.1}(stat)\ ^{+1.0}_{-0.7}(sys)$ pb

σ (double tag) =

$5.4 \pm 2.2(stat) \pm 1.1\ (sys)$ pb

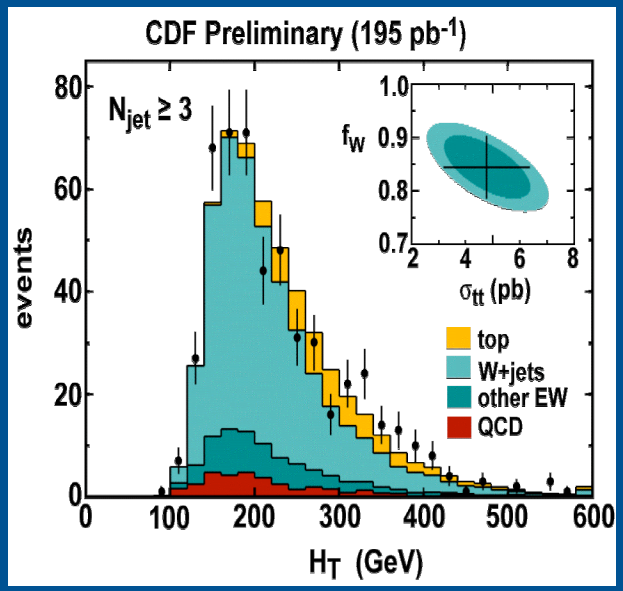
Soft-Muon-Tag



$\sigma = 4.1\ ^{+4.0}_{-2.8} \pm 1.9$ pb

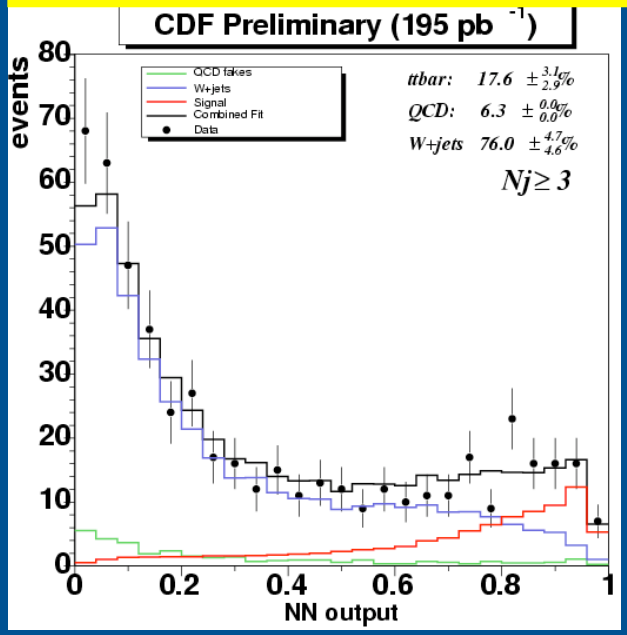
Results from Kinematic Fits

Fit 1 kinematic shape



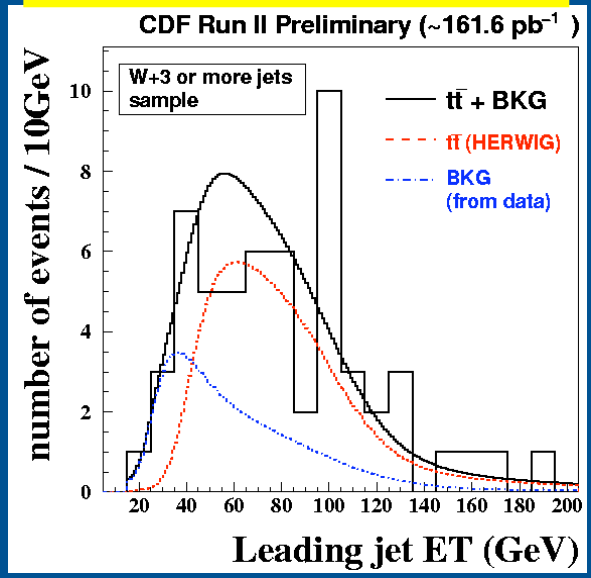
$\sigma_{t\bar{t}} = 4.7 \pm 1.6 \pm 1.8$ pb

Use 7 kinematic variables, fit NN output



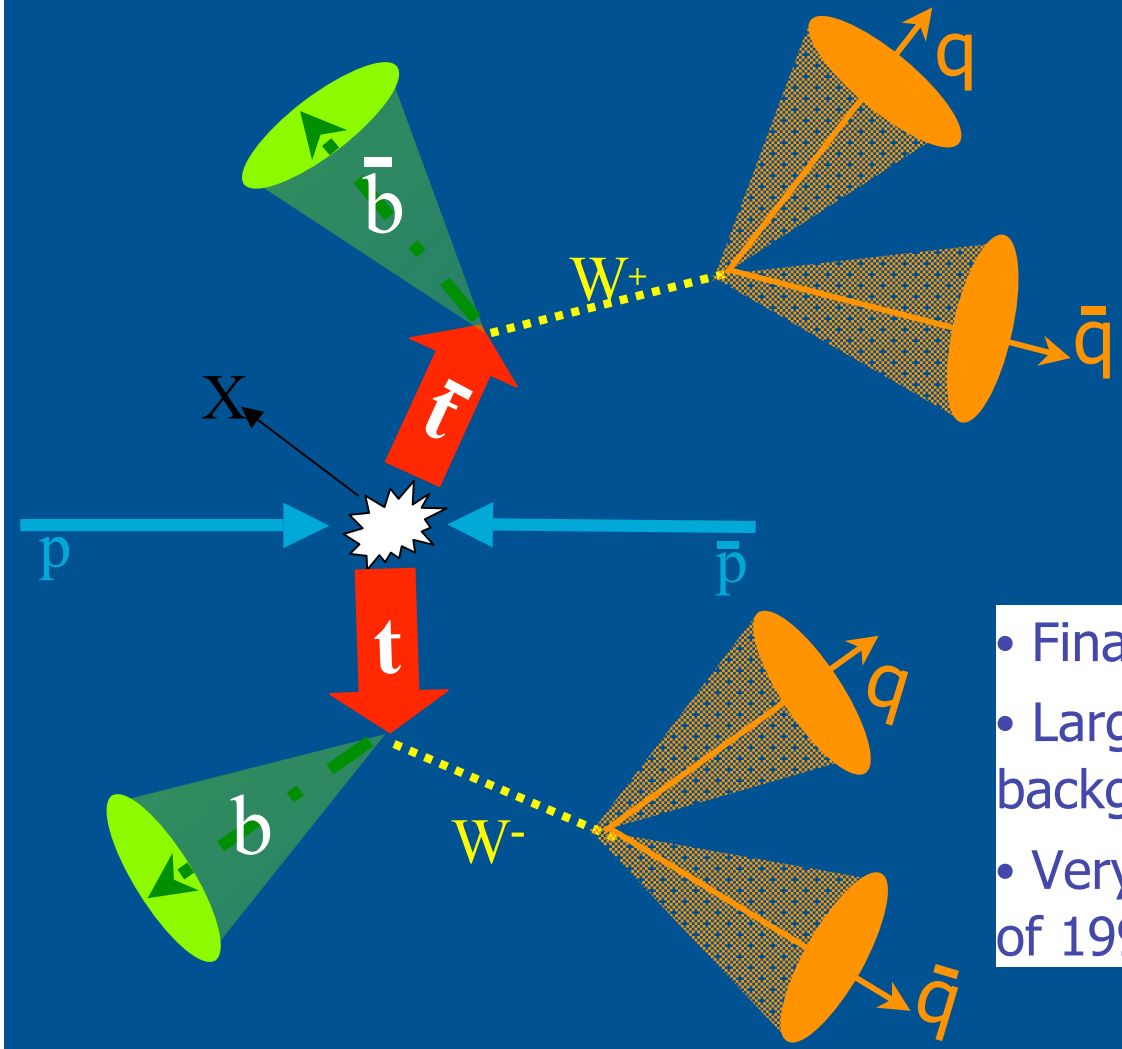
$\sigma_{t\bar{t}} = 6.7 \pm 1.1 \pm 1.6$ pb

Require >=1 b-tag, fit 1 kinematic shape



$\sigma_{t\bar{t}} = 6.0^{+1.5}_{-1.8} \pm 0.8$ pb

All-Hadronic Channel
Find a needle in a haystack (QCD)

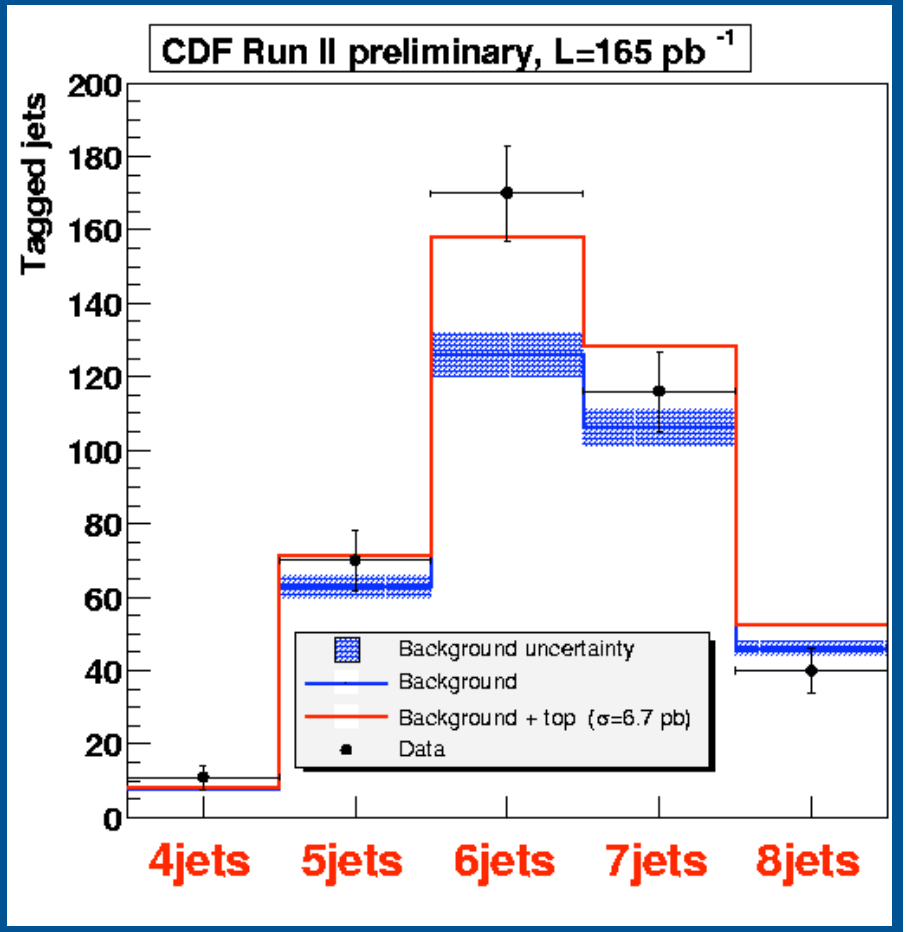


- Final state: 6 jets, 2 b-quark jets
- Large statistics, but huge QCD backgrounds
- Very difficult, but was already part of 1995 discovery

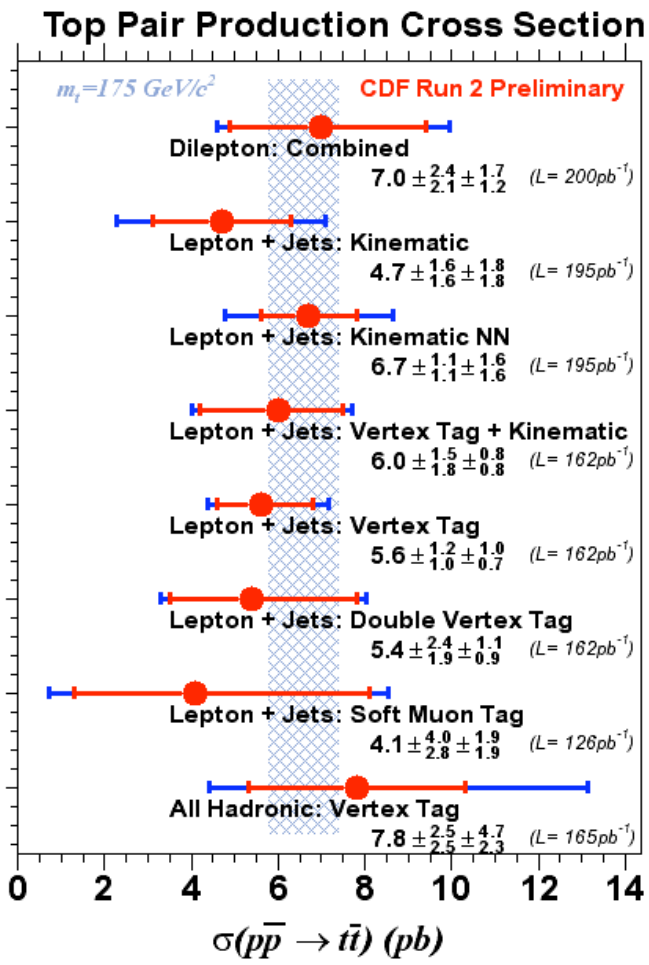
All-Hadronic Results

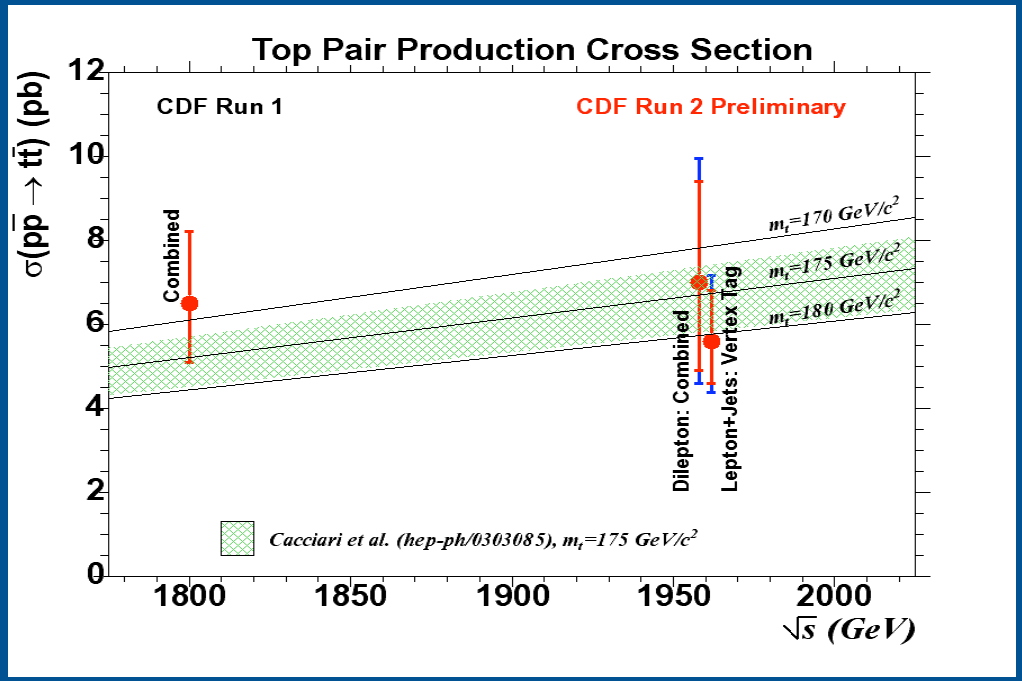
- Use dedicated trigger (4 jets > 15 GeV and sumEt >125 GeV)
- S/B of 1/2500 increased to 1/24 with sumEt > 320 GeV and topo. cuts: aplanarity, centrality
- Require 6 to 8 jets, and b-tags

$$\sigma = 7.8^{+2.5}_{-1.0}(stat)\ ^{+4.7}_{-2.3}(sys)\ \text{pb}$$



Cross Section Summary





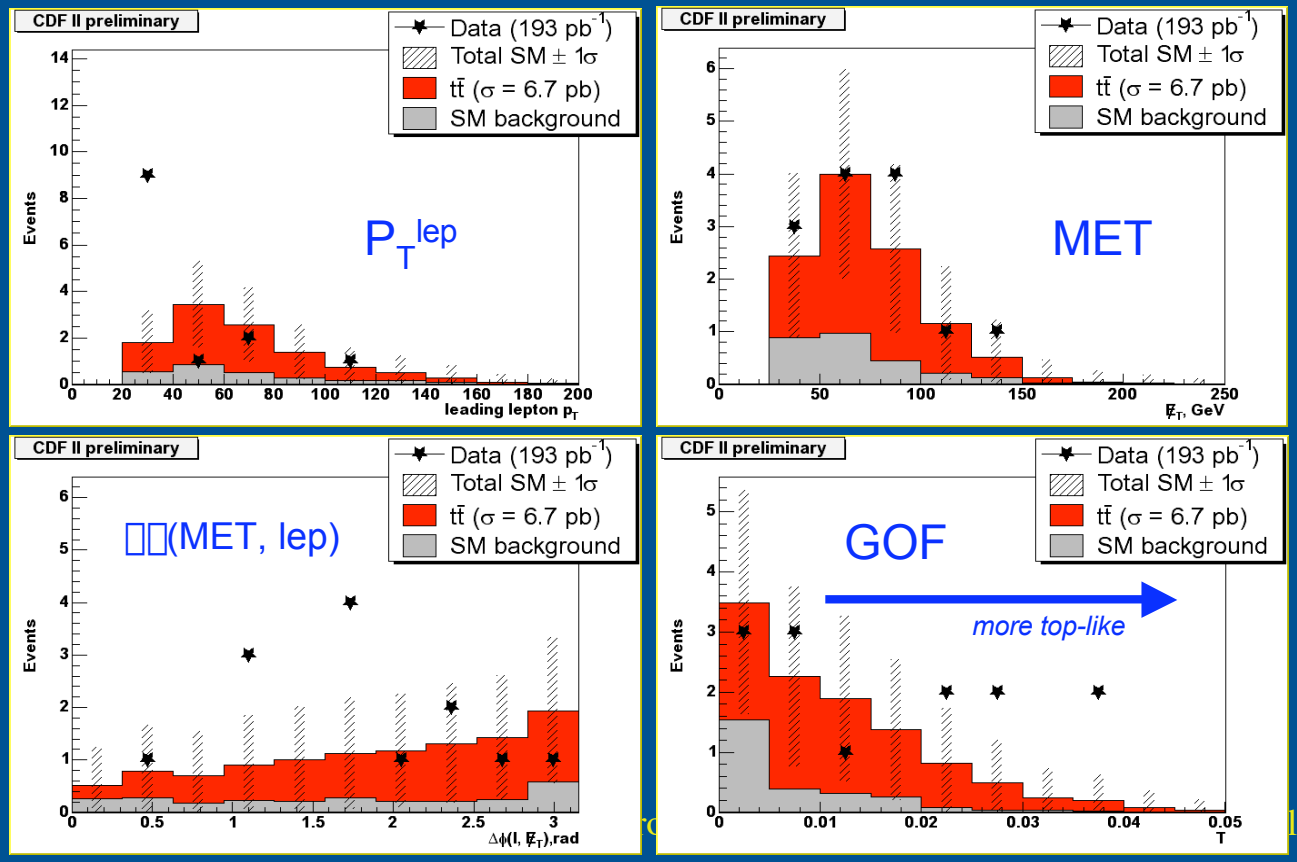
Observed cross sections consistent with each other and with the SM prediction for m_t=175 GeV/c²:

$$\sigma(t\bar{t}) = 6.7^{+0.7}_{-0.9}\ \text{pb}$$

Bonciani *et al., Nucl. Phys.* **B529**, 424 (1998)
Kidonakis and Vogt, *Phys. Rev.* **D68**, 114014 (2003)

Dilepton Kinematics

- Intriguing event kinematics seen in Run I: cluster of events at large E_T^{miss}, at large total energy (H_T), at small lepton P_T
- Suggestion that the events are better described by cascade decays of heavy squarks [Barnett and Hall, *Phys. Rev. Lett.* **77** 3506 (1996)]
- Develop search for this kind of anomaly in Run II



- Probability of consistency w/ SM (based on KS probabilities) = 1.0-4.5%
- Low probability driven by excess of *low*-p_T leptons --- likely fluctuation of top

Top Branching Ratios

- Does top decay into something besides Wb?
  - Like Xb, where X→ qq'?
    Or Yb, where Y→ l?
  - If so, then dilepton and l+jets cross sections will disagree
- Measure the ratio of cross sections $R_{\sigma}=\sigma_{ll}/\sigma_{lj}$

$$R_{\sigma} = 1.45^{+0.83}_{-0.55}$$

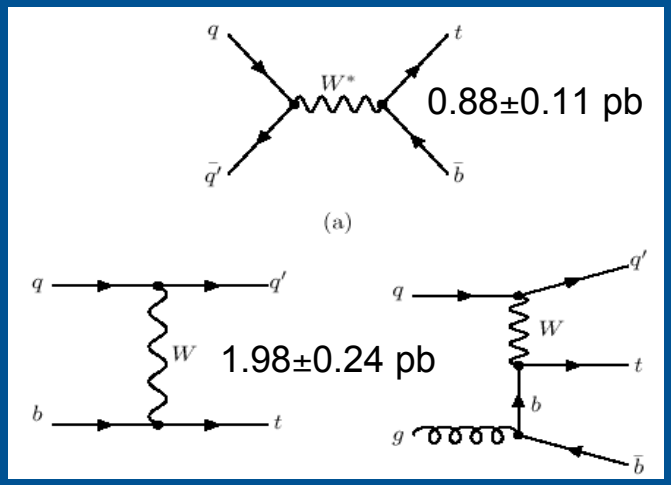
BR(t→ Xb) < 0.46 @ 95% CL
BR(t→ Yb) < 0.47 @ 95% CL

- Assuming three-generation CKM unitarity, $|V_{tb}|=0.999$:
  → $b=BR(t\to Wb)/BR(t\to Wq) > 0.998$
- Can measure "b" by checking the b-quark content of the top sample --- is it "polluted" with light quarks?
- Look at different samples (3 or ≥4 jets, 1 or 2 b-tags) and build combined likelihood from predicted and observed events

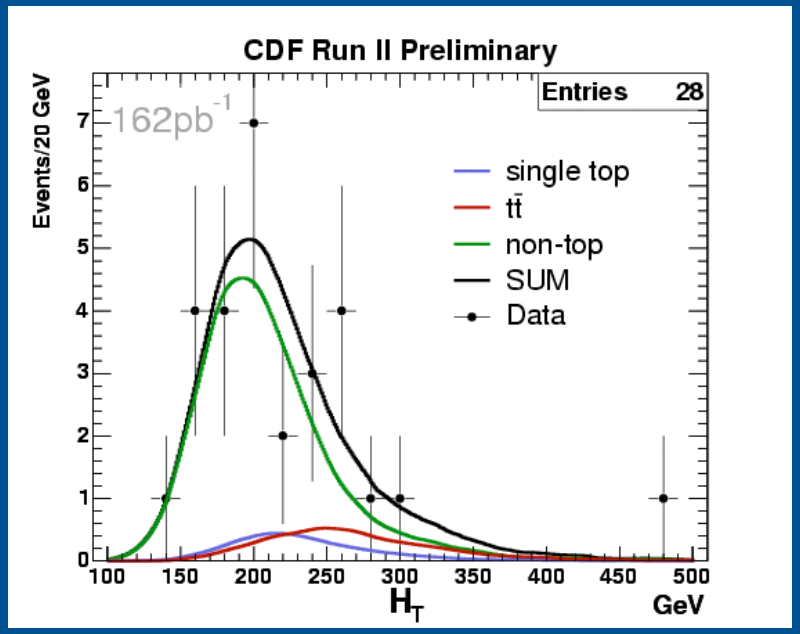
$$b = 0.54^{+0.49}_{-0.39}$$

Immediate improvements: bringing in dilepton samples, no-tag samples

Search for Single Top



- Direct determination of $|V_{tb}|^2$
- Sensitive to new physics:
  - s-channel: new charged gauge bosons
  - t-channel: anomalous couplings, FCNC
- Search for W+2 jets, tag one b
- Likelihood fit to H_T (combined), $Q_l^* \kappa_q$ (t-channel)



95% CL limits:
Combined: □ < 13.7 pb
t-channel: □ < 8.5 pb

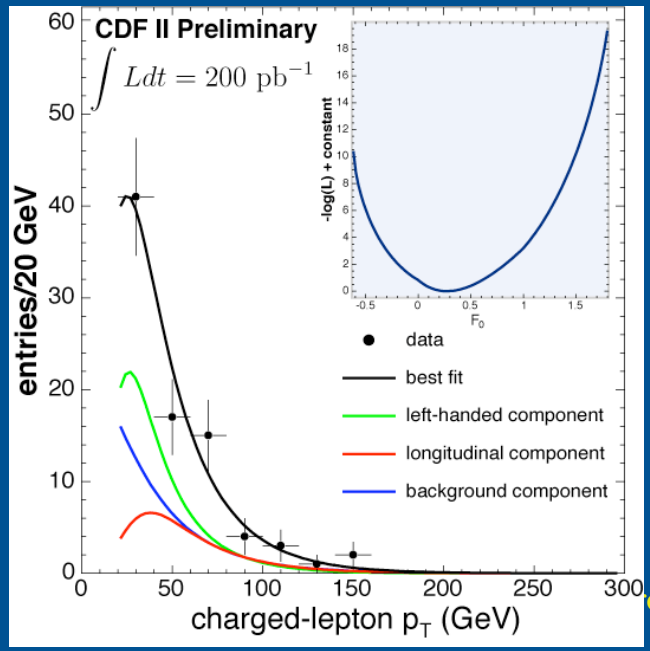
Run II (2 fb^{-1}) goals:
□□(tbX): 26%
□□(t→Wb): 28%
□|Vtb|: 14%

W Helicity

- W couples only to LH particles (RH antiparticles)
- This together with angular momentum conservation allows top decays only into LH (negative-helicity) or longitudinally-polarized (0-helicity) W bosons

$$F_0 = \frac{\Gamma(t \to W_0 b)}{\Gamma(t \to W_0 b) + \Gamma(t \to W_T b)} = \frac{1}{1 + 2(m_W / m_t)^2} = 0.70$$

- By measuring F_0 we test the V-A structure of the weak interaction at high energy
- Helicity of W manifests itself in decay product kinematics



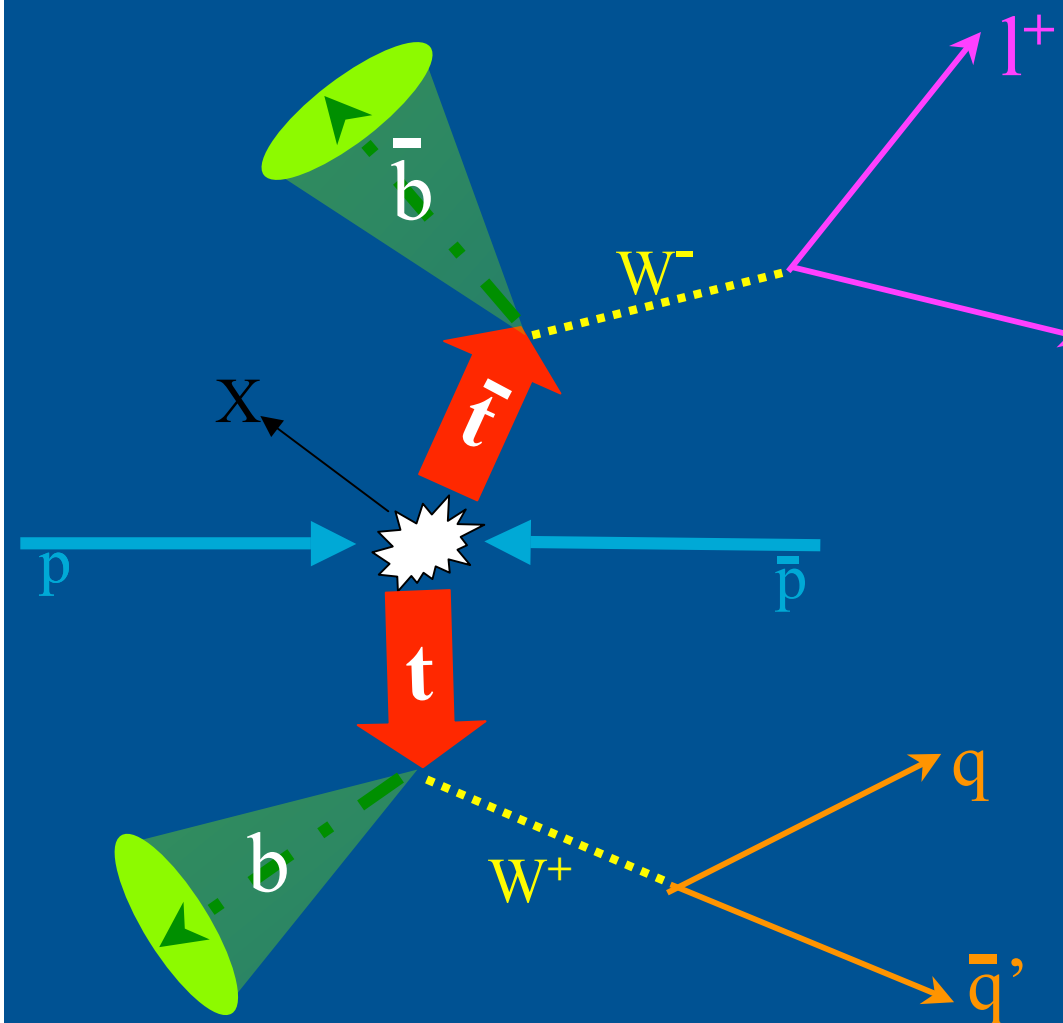
- Results in l+jets and dileptons:
  - Fit lepton p_T spectrum for W_0 fraction
- Result: $F_0 = 0.27^{+0.35}_{-0.24}$
- Low-p_T lepton excess seen in dileptons pulls result down (l+jets sample only: $F_0 = 0.88^{+0.12}_{-0.47}$)

Conclusions

- Top is re-established in Run II at CDF
- Consistent cross section measurements in all channels and with a variety of methods
- Single top needs ~ 4x more luminosity
- So far the top quark at CDF behaves like Standard Model top
- New results with more luminosity coming soon !

BACKUPS

Top Physics



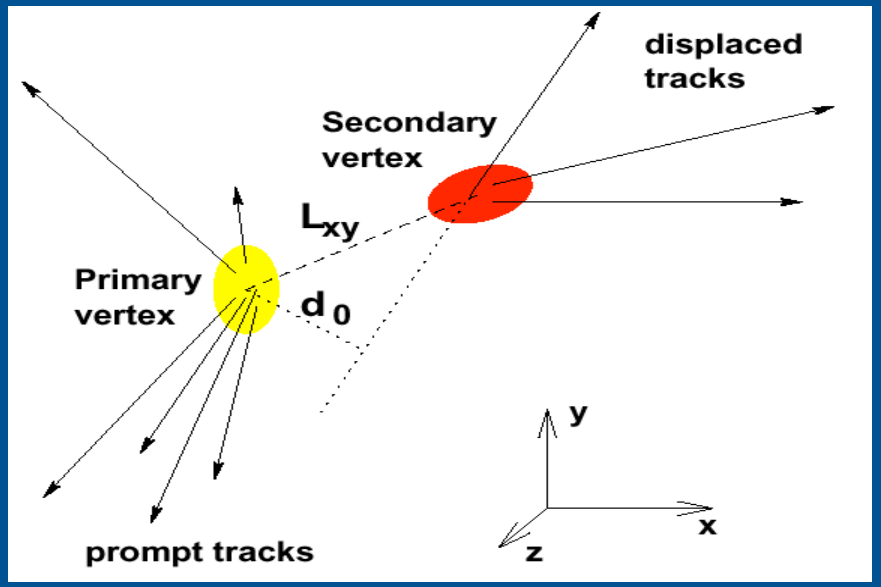
- **Analysis channels:**
- Production mechanism
- Search for resonant production
- Production kinematics
- Top mass measurement
- Top quark charge
- Top spin polarization, W helicity
- Top decay modes
- Branching ratios
- |Vtb|
- Search for rare decays t->Zc/γc, t->WZb, ...
- Search for non-SM decays: t->H$^{+/-}$, t->$\tilde{t}$, ...

- **Dileptons:** BR=11% (ee/eμ/μμ only=5%) cleanest sample, lowest statistics
- **Lepton+Jets:** BR=44% (e/μ+jets=29%) golden channel w/ high statistics and reasonable S/B
- **All Hadronic:** BR=44% most challenging channel w/ high statistics but large backgrounds

B-Tagging

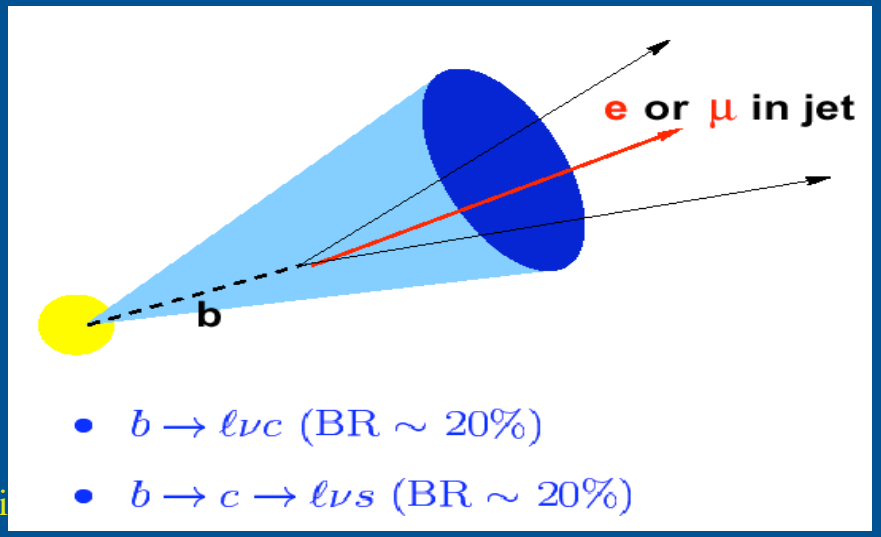
- *Secondary vertex tag*: displaced vertex reconstruction with silicon detector: B hadrons travel ~3mm before decay w/ large charged track multiplicity

Top Event Tag Efficiency	55%
False Tag Rate (QCD jets)	0.5%



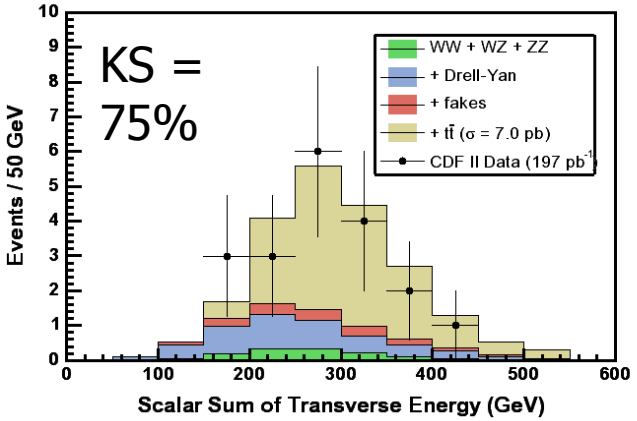
- *Soft lepton tag*: identify (lower-P_T) lepton from semi-leptonic b decays

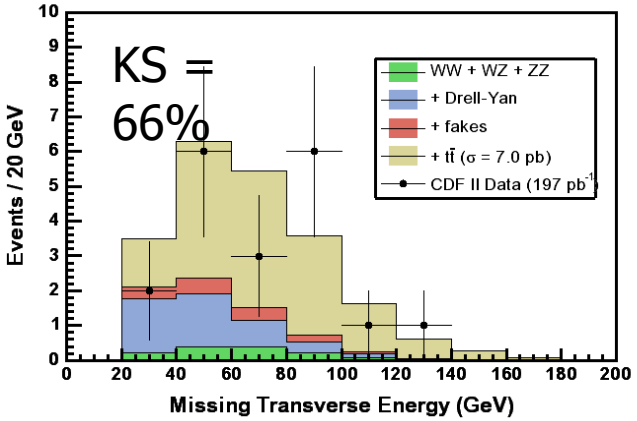
Top Event Tag Efficiency	15%
False Tag Rate (QCD jets)	3.6%



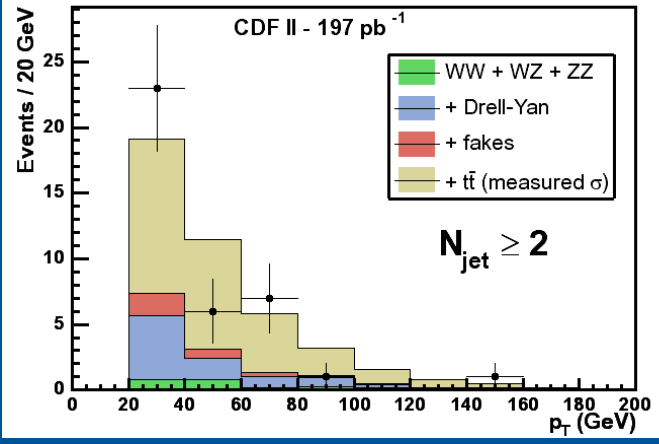
- $b \to \ell\nu c$ (BR $\sim$ 20%)
- $b \to c \to \ell\nu s$ (BR $\sim$ 20%)

Dilepton Kinematics





Leptons Transverse Momentum

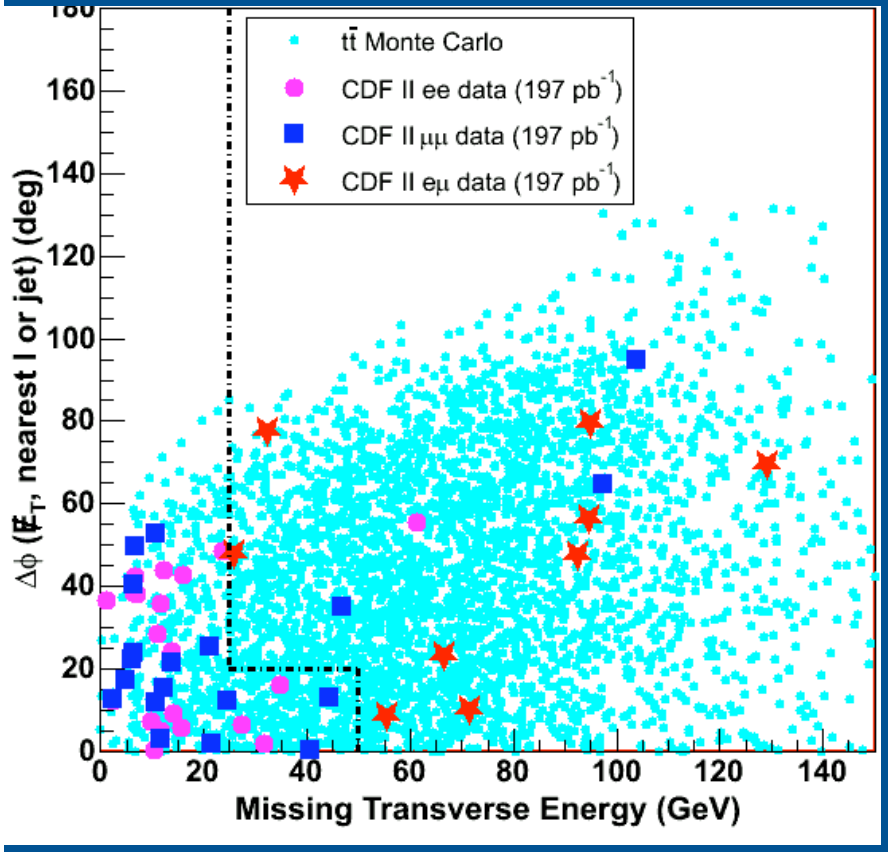


With larger statistics, we can start going beyond counting experiments to do shape tests on our selected sample.

→ Data follow expected distribution of top + background

Dilepton Flavor distribution

Use sample with two identified leptons to look at flavor distribution



channel	Expected (scaled to 13 total obsv'd)	Observed
ee	3.3 ± 0.5	1
□□	2.8 ± 0.5	3
e□	6.8 ± 0.8	9

→ Flavor distribution is consistent with SM expectation.